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IR OPTIMIZATION, DID AND ANTI-DID*

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Abstract

In this paper, we discuss optimization of the larger crossing angle Interaction Region of the Linear Collider, where specially shaped transverse field of the Detector Integrated Dipole can be reversed and adjusted to optimize trajectories of the low energy pairs, so that their majority would be directed into the extraction exit hole. This decreases the backscattering and makes background in 14mrad IR to be similar to background in 2mrad IR.

INTRODUCTION

In the machines with crossing angle, the detector solenoid field results in a deviation of the vertical trajectory and in a small vertical angle at the IP (about 100 μrad for crossing angle of 20mrad). This angle is anti-symmetrical for e+e- machines and does not affect the luminosity. The vertical angle at the IP also causes rotation of the spin by about a degree resulting in a misalignment of the spin orientation at the IP with respect to the upstream polarimeter. The Detector Integrated Dipole (DID) is a pair of coils wound on the detector solenoid which creates sine-like transverse field, giving the possibility to adjust the beam trajectories near the interaction region [1]. The DID was originally suggested as a way to compensate the vertical angle at the IP, as illustrated in Fig.1, and avoid spin misalignment.

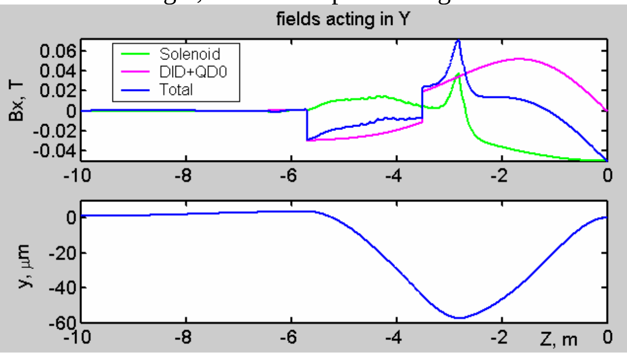

Figure 1: Compensation of the incoming beam vertical angle at the IP with DID and dipole corrector of the QD0 quadrupole. Field acting in Y (top) and vertical trajectory (bottom). SiD detector, crossing angle 20mrad, IP at z=0.

The DID field creates U-like distortion of the central field line of the detector solenoid, and compensation of the vertical angle of the incoming beam is in fact equivalent to aligning the field line, effectively, with the incoming beam. This increases the transverse field seen by the outgoing beam, in particular the beamstrahlung pairs. The high energy pairs continue along the initial direction of the beam, while the low energy pairs spiral around the field line and disperse, as shown in Figs.2-3.

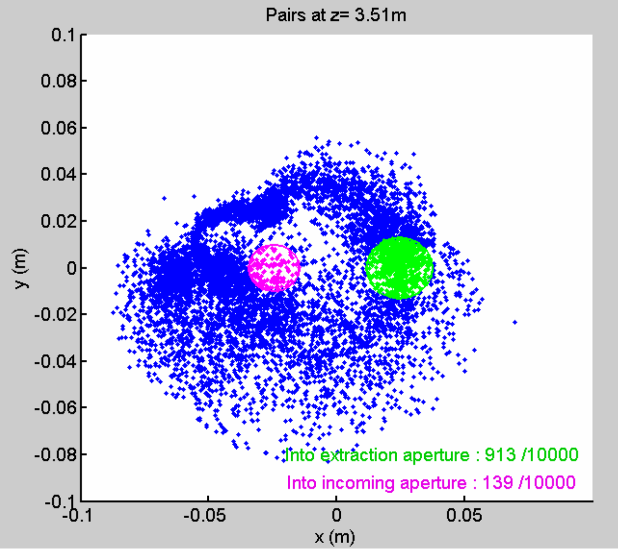

Figure 2: Distribution of pairs at 3.5m from IP in SiD detector when DID is used to compensate the vertical IP angle of the incoming beam. The incoming and outgoing apertures are shown by magenta and green colors.

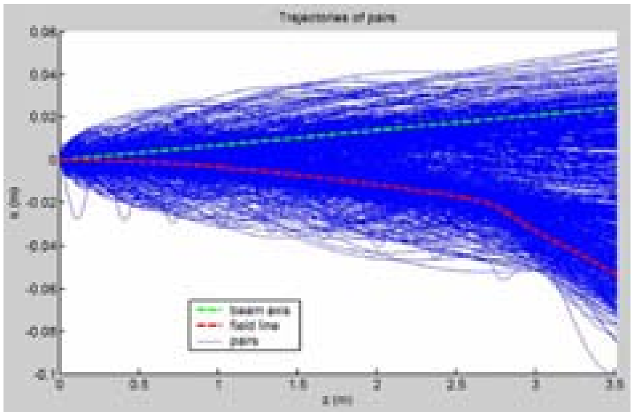

Figure 3: Trajectories of pairs coming from the IP in SiD detector when DID is used to compensate the vertical IP angle of the incoming beam. The high energy pairs follow the beam axis (green dashed line) while the low energy pairs spiral around the field line (red dashed line).

Large spread of the pairs on the face of BEAMCAL resulted in backscattering and increase of background photon hits in TPC (Time Projection Chamber). The number of photon hits in TPC increased several times and the effect was especially dramatic when the outgoing aperture was not optimized [2].

The technology of compact direct wind SC magnets allows reducing the crossing angle to 14mrad [3]. With reduced crossing angle, the synchrotron radiation (SR) effects significantly decreased ($\Delta\sigma_{sr}\sim\theta_c^{5/2}$), simplifying use of reversed DID (anti-DID) described below.

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ANTI-DID

While the normal polarity of DID allows to compensate locally the effect of crossing the solenoid field for the incoming beam, the anti-DID (reversed polarity) allows to effectively zero the crossing angle for the outgoing beam (and pairs) – the U shaped distortion of the field lines is adjusted to guide the low energy pairs to the extraction aperture as shown in Fig.4.

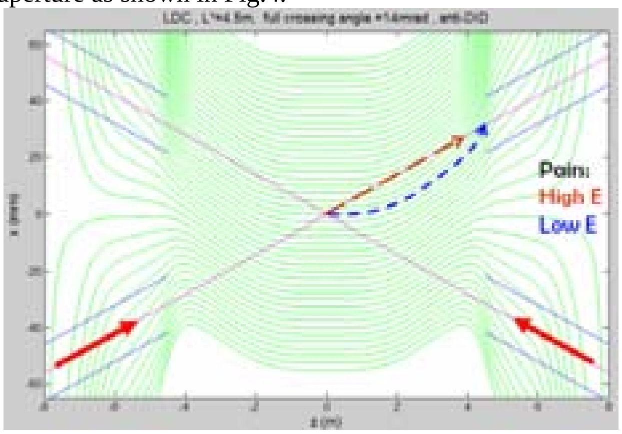

Figure 4: Field lines in LDC detector with anti-DID. The anti-DID field shape has flattened central region, to ease TPC calibration. The total crossing angle is 14mrad.

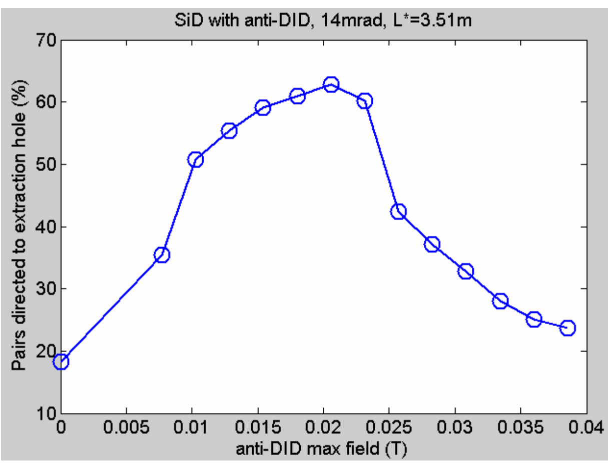

Figure 5: Fraction of pairs directed into extraction aperture in SiD versus anti-DID maximum field.

Figs.5-7 give quantitative results of tracking of beamstrahlung pairs in realistic solenoid field of SiD detector taking into account the anti-DID field. The shape of anti-DID field was obtained earlier, in simulations with 2D and 3D magnetic models [1]. The pairs were obtained from beam-beam simulations by Guinea-Pig program [3].

Fig.5 shows the fraction of pairs entering the extraction aperture versus maximum field of anti-DID. Fig.6 and Fig.7 corresponds to the optimal strength of anti-DID and show distribution of pairs 3.5m from the IP and trajectories of the pairs along the SiD detector. One can see that more than 60% of the pairs can be directed into the extraction aperture.

Similar optimization, as for SiD, can be done for other two detectors, GLD and LDC. In this optimization, we used real solenoid field maps, and the shape of anti-DID field used for GLD and LDC was specifically optimized for these larger detectors with TPC (see below). We used ILC final focus optics with different L* (distance between IP and first quadrupole of FD): L*=3.51m for SiD and L*=4.51m for GLD and LDC. The Final Doublet was properly overlapped with the solenoid field.

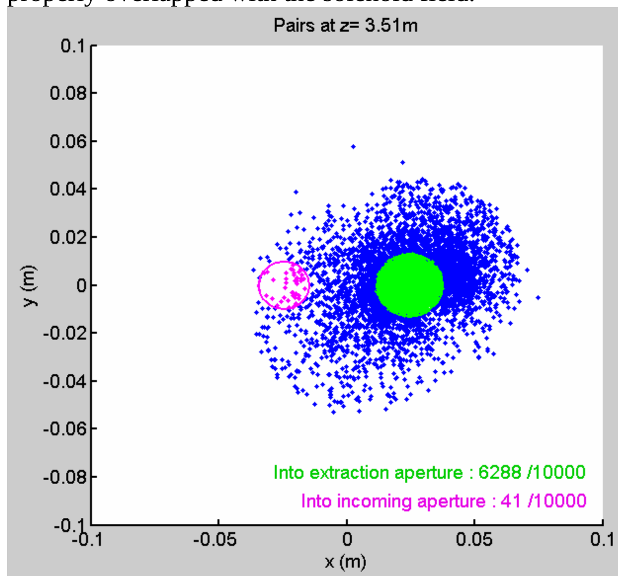

Figure 6: Distribution of pairs at 3.5m from IP in SiD detector when anti-DID is adjusted to direct pairs to the extraction hole. The incoming and outgoing apertures are shown by magenta and green colors.

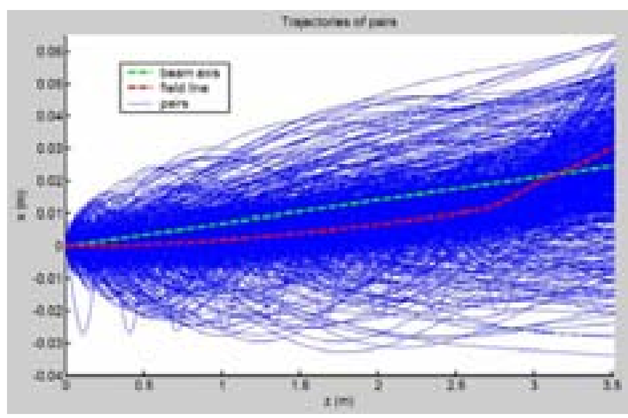

Figure 7: Trajectories of pairs in SiD with anti-DID.

	B_t ,Gs	θ_{IP} , μr	$\Delta\sigma_{sr}$, nm	L , %	P_{ex}, %
SiD	205	-102	0.32	99.8	63
GLD	236	-96	0.65	>99	51
LDC	235	-122	1.01	98	49
LDC	354	-138	1.67	95	62

Table 1: Maximum field of anti-DID B_t, angle of the incoming beam at the IP θ_{IP}, SR beam size growth $\Delta\sigma_{sr}$ (to be added to σ_{y0}=5nm in quadratures), luminosity L taking into account SR effects, fraction of pairs P_{ex} directed to extraction aperture. Total crossing angle is 14mrad.

The results of these optimizations are summarized in the Table 1 in terms of the optimal field of anti-DID, number of pairs at extraction aperture, SR beam size growth and its effect on the luminosity. The vertical angle of the incoming beam at the IP (which is now left uncorrected) is also shown in this table.

One can see that in all cases one can direct more than half of the pairs into the extraction aperture. In LDC detector, with its 4Tesla field, the optimal anti-DID would increase SR effects noticeably and could result in loss of 5% of luminosity. Decreasing the anti-DID strength by one third from the optimum could reduce the effect on the luminosity to 2% while still directing about 50% of pairs into the extraction aperture.

As clear from the above figures, the anti-DID increases the transverse field seen by the incoming beam and increases SR effects. Comparing the angle of incoming beam at the IP without and with anti-DID, one can find that the anti-DID increases the effective crossing angle for the incoming beam by 40-50%. If the total crossing angle is 14mrad, the effective crossing angle for the incoming beam is still about twenty mrad.

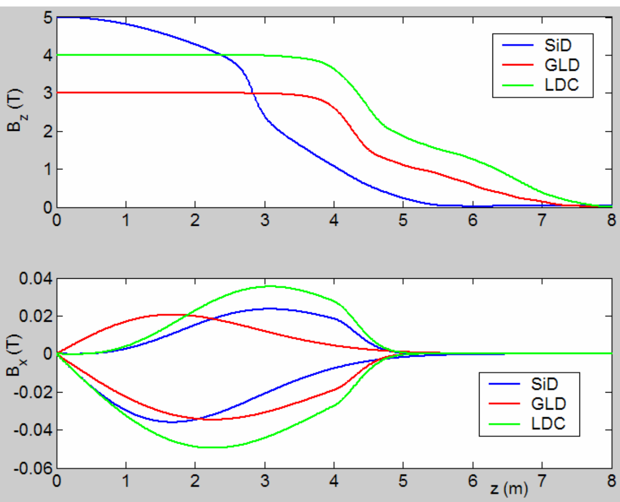

Figure 8: Top plot: detector fields. Bottom plot: field of anti-DID (positive curves) in comparison with DID (negative curves) for 14mrad crossing angles. The DID field corresponds to earlier results, where flattening of the field in the central region was not yet implemented.

Finally, one need to note that the strength of anti-DID in comparison with DID is smaller by 30-40%, as illustrated in Fig.8 where the anti-DID fields are shown.

Vertical angle at the IP with anti-DID

With anti-DID, it is naturally to leave the vertical angle at the IP uncorrected and to zero only the IP position, using dipole corrector in FD. The trajectory in this case would look like the one shown in Fig.9. (The angle at the exit from the detector will be zeroed by correctors at the entrance of the extraction line).

The vertical angle at the IP still can be compensated, if needed for polarization, less locally, using dipole fields in the Final Doublet correctors. One can consider zeroing only the vertical angle but allowing offset of the IP position; zeroing both the vertical angle and IP position.

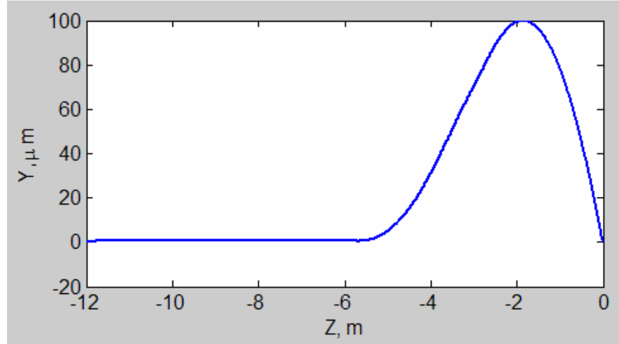

Figure 9: Vertical trajectory of the incoming beam in SiD with anti-DID and crossing angle 14mrad. IP is at z=0.

Although further optimization may be possible, analysis of SR effects shows that in anti-DID case, for present parameters and for considered detector models it is not practical to zero both IP angle and position. Due to non-local character of correction the deviation of the orbit and SR effects become large and luminosity loss even for SiD would be about 40%, and larger for other detectors.

Another option, to zero only the angle, may however be feasible (illustrated in Fig.10). The vertical orbit deviation is increased but SR effects are tolerable. In the SiD detector with anti-DID and 14mrad crossing angle the SR results in $\Delta\sigma_{sr}$ =1.2nm and the loss of luminosity due to SR is about 2.8% (the loss in GLD or LDC can be estimated as 2-6% knowing the uncorrected angle at the IP from Table.1). It is also clear from Fig.10 that for the two beams to collide, the incoming vertical orbits of the two beams should be shifted.

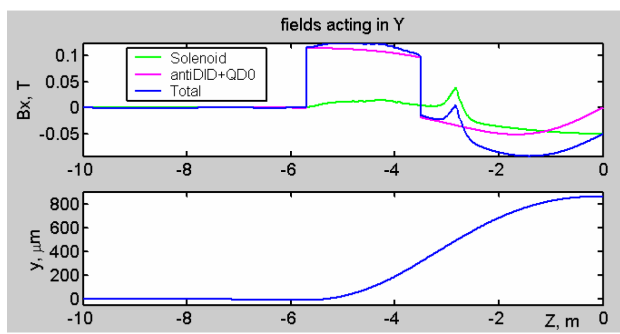

Figure 10: Fields acting in Y and vertical trajectory in SiD with anti-DID when dipole correctors in FD were adjusted to zero the IP angle. Shown for crossing angle of 20mrad and for anti-DID stronger than the optimum.

So, it is in principle possible to use anti-DID and simultaneously zero the IP angle to align the spin in parallel to the upstream polarimeter. However, the necessity to zero (or even to reduce) the vertical IP angle is being reevaluated [4] and may not be necessary.

Indeed, the procedure of setting the IP beam polarization would involve maximization of polarization at the upstream polarimeter (which can be done with accuracy θ_P =25mrad rms for spin angle misalignment [5]) and taking into account that the IP polarization will be smaller by a known amount due to vertical angle at the IP. The spin precession due to finite vertical angle at the IP is

$\theta_S = \gamma\,\theta_{IP}\,(g/2-1) = \theta_{IP}\,E\,(\mathrm{GeV}) / 0.44065$. The maximum practical angle from Table.1 is θ_{IP} =122μrad which for the spin angle gives θ_S =69mrad (and does not depend on energy, since for fixed detector field θ_{IP} ~1/E). The polarization behaves as cosine of the angles $\cos(\theta_P+\theta_S)$ and thus it does not allow full factorization of the effects of the angles at the IP and at the upstream polarimeter. In the assumption that $\theta_P<\theta_S$ and that the beam orbit angle at the IP can be measured with precision better than about 10μrad, the precision of polarization knowledge at the IP with respect to measurement at the upstream polarimeter is dominated by the spin misalignment at the polarimeter and could be expressed as $\mathrm{rms}(\theta_P)*\theta_S$. This gives about 0.17% rms for the polarization precision which is better than the target goal of 0.25%.

Moreover, when the vertical IP angle is not corrected, one can still tilt the beam orbit in the downstream polarimeter (where the SR beam emittance increase does not matter, in contrary to the upstream polarimeter) to match the IP angle.

These considerations suggest that while it is possible to zero or decrease the vertical angle at the IP, this may not be necessary, since polarization precision goals can be met.

Anti-DID and TPC Operation

Let us discuss compatibility of DID (or anti-DID) transverse field with Time Projection Chamber operation. Traditionally, TPC specify requirements for field uniformity with certain high precision. However, precise 3D field maps are used in tracking reconstructions anyway. Therefore, providing 3D map of solenoid field with DID (for several settings) would solve this particular TPC-DID concern. However, there is another issue related to TPC track-based calibration. It was suggested by Dan Peterson [6] that uniform magnetic field is required in some region about half-a-meter around the IP in order to perform a track-based calibration the magnetic field. Such uniform field region would allow isolating the effects of the field distortions on track trajectories from the effects of field distortions on the drift path. It was suggested [6] that the uniformity requirement is $dB/B < 4*10^{-4}$ for $|z| <$ 50 cm, while the uniformity is less important at larger z – the current DID design field of 0.07T at |z|= 2.2m (in LDC at 20mrad) would be acceptable. Details of TPC operations and specifics of the field-map requirements due to the anti-DID will be discussed in details in upcoming notes [7].

To address the above challenge, we suggested to modify the design of DID coils and construct the field using two coils, a shorter and a longer one. The 3D models of the coils were created, with the same radius of 3.5m and with pattern length of 1.5m and 3m, as illustrated in Fig.11. The resulting field was used in the optimization.

In the field calculation the effect of detector iron was neglected (we checked earlier that this is a reasonable approximation) but eventually the iron should be included in detailed simulations. The "short" and "long" DID coils were combined and the currents were adjusted to flatten the field in the center. It was found that in order to flatten the field, the current ratio for the short/long coils should be equal to -1.245, and both currents need to be increased 2.5 times to have the same max field for the combined DID as for single coil.

With combined DID coil, reduction of the field in the central region (|z| < 0.5m) was found to be about 65 times with respect to the single long DID, as illustrated in Fig.12. Such modification of the DID field shape should ease TPC calibration. The DID field shape used in this paper for GLD and LDC was similar to the one shown in Fig.12, but had sharper decay after |z|>5m due to effect of the iron of the detector yoke (shown in Fig.8).

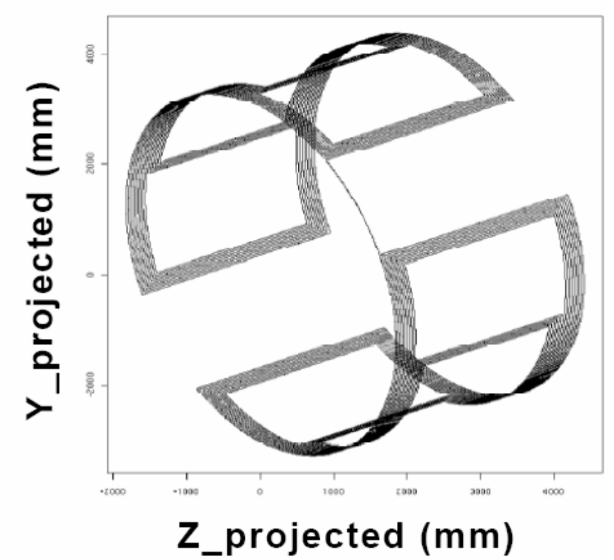

Figure 11: 3D model of a longer DID coil. Coil radius is R=3.5m, length 3m, effective magnetic length 3.97m. The shorter DID coil had the same radius and length of 1.5m.

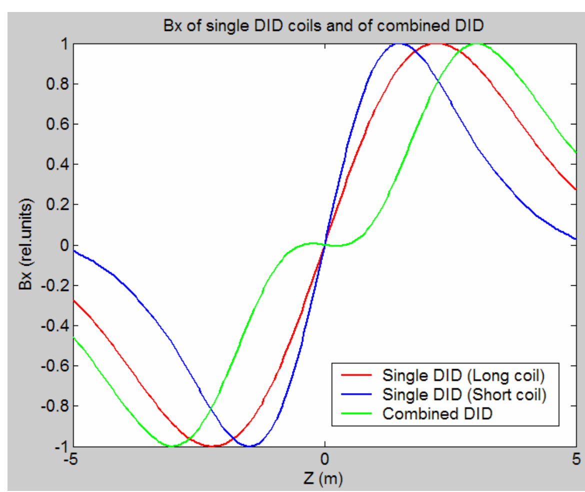

Figure 12: Field of the shorter (1.5m pattern length) and longer (3m) DID coils and the field of the combined DID coil optimized for detectors with TPC.

Background in SiD with Anti-DID

GEANT model of SiD with 14mrad IR was created [8], as illustrated in Fig.13.

Background calculations include counting hits in the vertex detector (VXD) and in the tracker. The ILC 500GeV CM nominal beam parameters were used in background calculations. The 14mrad IR calculations were also compared with 20mrad and 2mrad IR for SiD.

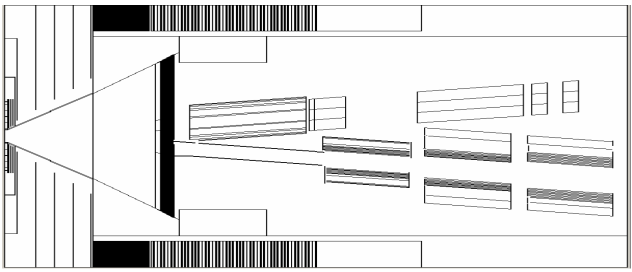

Figure 13: GEANT model of SiD with 14mrad crossing angle, with Final Doublet and extraction quadrupoles.

14mrad	14mrad+DID	14mrad+anti-DID	2mrad
1800	1900	830	720

Table 2: Number of photons going into SiD tracker per bunch crossing.

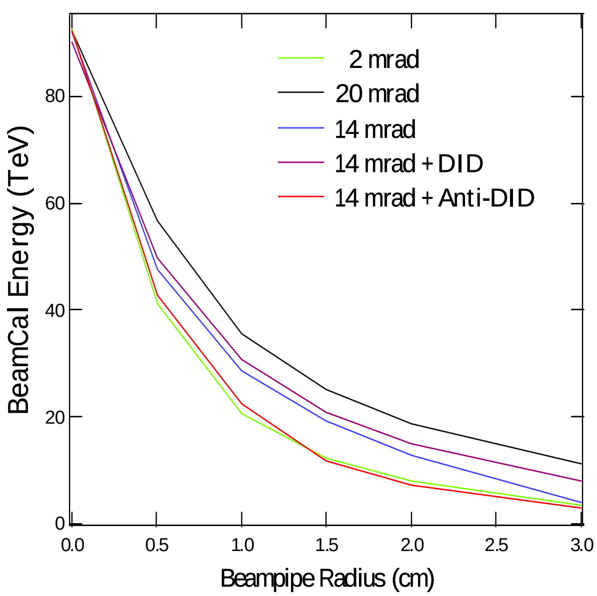

Figure 14: Total energy of beamstrahlung pairs hitting BEAMCAL versus radius, SiD with different crossing angle and with DID or anti-DID.

It was found that DID or anti-DID field settings have almost no effect on VXD hits. However, the total energy of pairs hitting into BEAMCAL was found to be smaller in 14 mrad crossing in comparison with 20mrad IR. It was found that the anti-DID can further reduce the energy to the 2 mrad crossing angle level, as illustrated in Fig.14. The number of secondary photons generated in BEAMCAL and going to the tracker is also smaller in 14mrad with anti-DID, and is about the same as in 2mrad, as shown in Table.2. Therefore, with anti-DID the background in 14mrad IR can be similar as in 2mrad IR. Similar optimizations and background calculations should be done for GLD and LDC detectors.

Application to 20mrad, to e-e- and $\gamma\gamma$

Scaling the results of the Table.1 to 20mrad crossing angle, one can easily see that the anti-DID can work fine for SiD and also for GLD with reduced anti-DID field, while it may be problematic for LCD with its large 4Tesla detector solenoid. However, the concept presented in this paper certainly can be further optimized. In particular, optimization of the anti-DID field shape and also of the way to make the dipole corrections in FD can be considered and may result in improved applicability of anti-DID for 20mrad for all considered detectors.

Finally, in the cases of e-e- or $\gamma\gamma$ collisions the vertical trajectories are symmetrical and the vertical angle must be compensated, either with DID (as in Fig.1) or with FD only (as in Fig.10). In the latter case the anti-DID could be applied to improve background.

SUMMARY

Application of anti-DID was considered for SiD, GLD and LDC for intermediate crossing angle 14 mrad. With optimized anti-DID strength, the number of pairs directed to extraction aperture is more than 50%. The maximum field of the optimal anti-DID is about 0.6 of DID. With anti-DID, the IP angle still can be zeroed or decreased, with less local correction, however, compensation of the vertical angle appears not necessary as the polarization precision goals can be met. The modified DID with flattened field in the central region was suggested for GLD and LDC, to ease TPC calibration. Background simulations with anti-DID show that photon flux toward tracker region is decreased and is same as in 2mrad IR.

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REFERENCES

[1] B. Parker, A. Seryi, Phys. Rev. ST Accel. Beams 8, 041001 (2005).
[2] K. Buesser, Pair Backgrounds, Snowmass 2005.
[3] D. Schulte, Guinea-Pig program.
[4] P. Bambade, K. Moenig, K. Moffeit, M. Woods, H. Yamamoto et al., private communication, November 2005.
[5] K. Moffeit, M. Woods, private communication, November 2005.
[6] D. Peterson in his private communication to W. Kozanecki, August 2005.
[7] D. Peterson, R. Settles, W. Wiedenmann, LC Notes in preparation.
[8] Y. Nosochkov, T. Maruyama, et al., in these proceedings, Nanobeam 2005.